LOW-TEMPERATURE CVD CARBON NANOTUBES ON GLASS PLATES FOR FLAT PANEL DISPLAY APPLICATIONS

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ABSTRACT

Low-temperature chemical vapor deposition processes were studied for coating carbon nanotubes on metal-coated glass plates. Thermal CVD in hydrocarbon mixtures was used for carbon nanotube deposition at temperatures between 300° C and 550° C. Carbon nanotubes deposited on metal coated glass plates were examined by SEM and analyzed using a pin to disk setup in an ultra high vacuum chamber for measuring the electron emission characteristics. Using a one-millimeter diameter tungsten rod with a hemispherical tip as the anode while the carbon nanotube coatings as the cathode, current-voltage characteristics of the carbon nanotube coatings were measured and used for calculating the electric field at which electron emission started as well as calculating the field enhancement factor of the carbon nanotubes. Field emission of electrons from carbon nanotubes starting from an electric field as low as 1.4 volts per micrometer has been achieved.

INTRODUCTION

In order to use carbon nanotubes as the electron field emitters for large-area plasma displays it is desirable that an inexpensive substrate such as a glass plate is used for carbon nanotube deposition. A conductive layer needs to be deposited on a glass plate before carbon nanotubes are coated onto the substrate and used as a cold cathode. Because of the low melting point of glass and the large mismatch in the coefficient of thermal expansion between metal and glass, the carbon nanotube deposition cannot be performed at too high a temperature that is considered acceptable for carbon nanotube coating on a metal substrate. The mismatch in coefficients of thermal expansion for metal coatings and glass makes the adhesion of coatings on glass more difficult when the glass plate has to be heated to a high temperature and then cooled down to the room temperature. Various low temperature CVD techniques are being studied to achieve low threshold field emission of electrons at a high emission current density. In this paper, the results based on thermal CVD techniques are presented.

EXPERIMENTS

Shown in Figure 1 is the schematic diagram for the thermal CVD reactor that was used for this study. Mixtures of acetylene and argon or nitrogen [1] were fed into a quartz tubing chamber that was evacuated by a mechanical pump. The chamber gas pressure was controlled by a throttle vale and a manometer pressure gauge. A resistive heater was used to heat the quartz

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Carbon nanotubes were deposited on metal coated and catalyst seeded glass plates in the temperature range from 300C to 550C using the thermal chemical vapor deposition technique in gas mixtures of acetylene and argon or nitrogen. Field emission of electrons from carbon nanotubes starting from an electric field as low as 1.4 volts per micrometer has been achieved.

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tubing and the substrate inside the tubing to a preset temperature. Copper, nickel, and Cobalt were used as the catalysts for the carbon nanotubes coating.

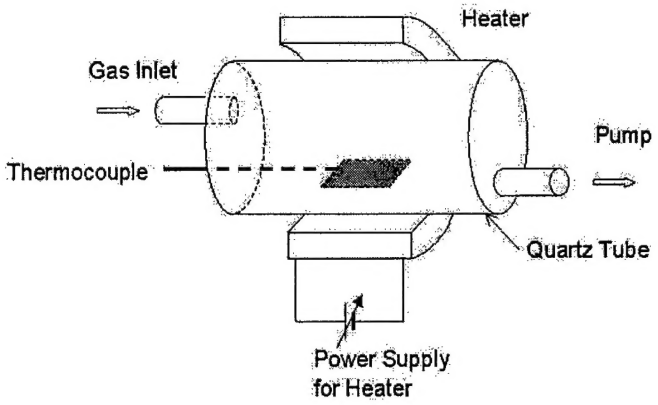

Figure 1. Schematic diagram for the thermal CVD reactor.

The carbon nanotube coated substrates were then loaded into a high vacuum chamber shown in figure 2 that was pumped down by a turbomolecular pump and an ion pump to a vacuum of about 1 x 10^{-7} Torr. The carbon nanotube coated substrate served as the cathode while a tungsten rod of one-millimeter diameter with the tip grounded into a hemispherical shape was used as the anode. The distance between the anode and the cathode was adjusted using a linear vacuum feedthrough to move the tungsten rod closer or farther from the carbon nanotube coated substrate. A desktop computer controlled the output of a high-voltage power supply for applying a voltage between the anode and the cathode. The electric field is calculated by dividing the applied voltage by the gap spacing between the anode and the cathode. The electron emission current was measured by a digital ammeter and recorded by the computer for further plotting and calculation.

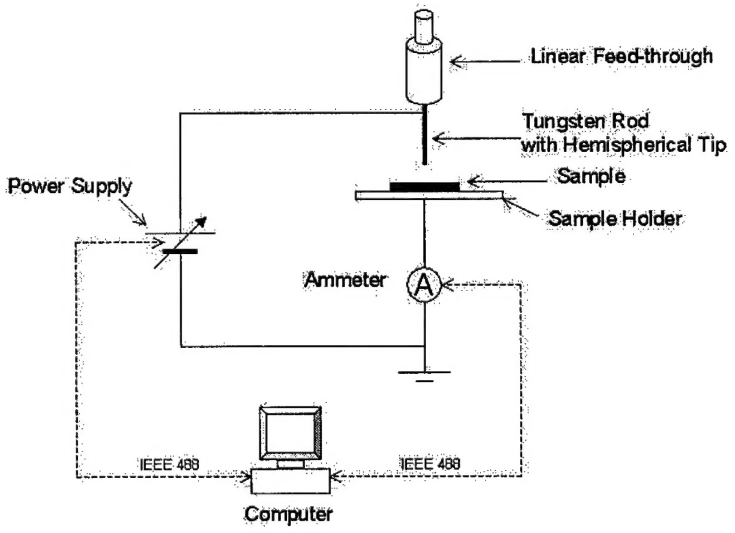

Figure 2. Experimental setup for electron emission measurement.

RESULTS

Shown in Figure 3 and 4 are the electron field emission characteristics for carbon nanotubes deposited on a copper coated glass plate at a temperature of 500° C for six hours. The gap spacing between the tungsten rod and the nanotube coating for electron emission measurement was 614 micrometers. Figure 3 shows that field emission of electrons started at an electric field equal to about 1.4 volts per micrometer. Electron emission current rose exponentially at electric field higher than the turn-on field of 1.4 volts per micrometer. The slope decreased at the electric field about 2 volts per micrometer and then started to become saturated.

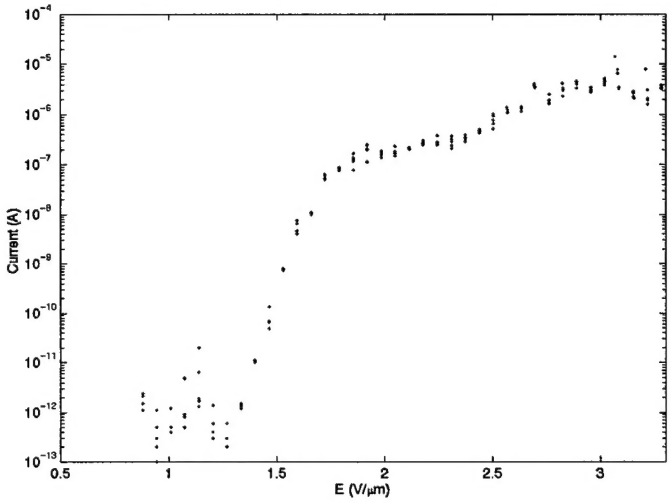

Figure 3. Field emission electron current vs. electric field.

The Fowler-Nordheim plot of the data is shown in Figure 4. A well-defined region of negative slope appears prior to the region of emission current saturation. The field enhancement factor was calculated from the negative slope using 5 eV emission barrier for graphite to be 1140.

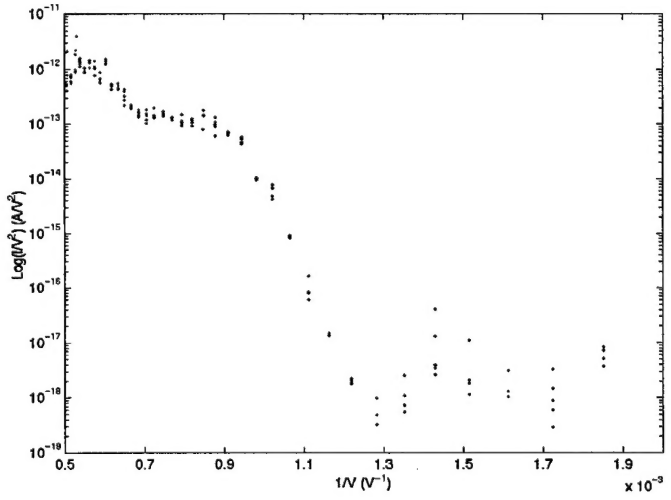

Figure 4. Fowler-Nordheim plot for field emission electron current.

Carbon nanotubes were deposited on copper coated glass plates at temperatures as low as 360° C. At a lower temperature, the deposition time needs to be longer. For example, a carbon nanotube deposited at 360° C for 11 hours resulted in an electron field emission threshold field being 2.3 volts per micrometer with the field enhancement factor being 913.

DISCUSSION

Thermal CVD technique provides a means for coating very large area substrates as well as mass production by coating multiple substrates simultaneously. From Figure 3 and 4, it is clear that the emission mechanism is of the Fowler-Nordheim type with electron field emission commencing at a low electric field because of the 1140 times of field enhancement factor [2-3]. The small diameter and very high aspect ratio of the carbon nanotube make it possible for the local electric field at the tip of the carbon nanotube to be more than one thousand times higher than that calculated by dividing the applied voltage by the distance between the anode and the carbon nanotube coating. With optimization of the coating conditions and the proper choice and applications of catalysts, high electron emission current exceeding 10m A per square centimeter at an electric field less than 1 volt per micrometer is expected.

CONCLUSIONS

Carbon nanotubes have been deposited on metal-coated glass plates at temperatures as low as 360° C. The threshold electric field for electron field emission from carbon nanotubes deposited on glass plates was measured to be as low as 1.4 volts per micrometer. The low threshold electric field and the capability of the thermal CVD technique for mass production of large-area carbon nanotube coated glass plates and other inexpensive substrates make this process promising for economic applications to flat panel displays. Field emission results from carbon nanotube coatings showed clearly Fowler-Nordheim behavior. Further research is being conducted to optimize the carbon nanotube coating process for achieving high current density electron field emission.

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